Operating Characteristics and Performance of a Busway Transit Station

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1 Introduction

Queensland Transport and Brisbane City Council are working on providing dedicated busway corridors to increase public transport patronage by reducing the travel time and improving reliability and capacity. However, as the passenger numbers increase, bus delays at busway stations are increasing. If this problem of bus delays at busway stations is not addressed, it will become an impediment to the success of busways. It is therefore necessary to develop a methodology to quantify the operating efficiency of the existing busway stations and their future potential.

A busway is a dedicated high speed corridor for buses, as public transport vehicles, to remove the influence of road traffic conditions such as traffic congestion including delays at intersections. By increasing the journey speed and reliability of the buses, public transport mode share should improve. Busway stations on the system are the connectors between passengers and vehicles and if not properly operated, these connectors become the bottlenecks of the whole network.

Very little research relating the efficiency of passenger – bus interaction with delays at the busway stations has been published. The delay caused by passenger – bus interaction can cause delays to other buses using the platform.

Demand for public transport in Brisbane is increasing, mainly because of the introduction of busway network and increase in fuel price. Many high frequency buses are already running full during the peak hours, leaving passengers behind at many intermediate busway stations. The effect of this additional passenger delay is therefore necessary to be taken into account while evaluating the busway station.

In this paper, the problem statement is formulated which is followed by the proposed methodology. A pilot study carried out at Mater Hill Busway station on the South East Busway, Brisbane is presented to illustrate the methodology. The paper quantifies the operational efficiency of the busway station with respect to bus dwell times.

2 Bus operations at busway station platforms and theory

The time a bus occupies a station consists of the following:

- The time spent in queue until the bus reaches the loading area where it will serve passengers.
- Dwell time including time for passengers to reach the bus door at its loading area position, time to serve passengers through the busiest door, and time to open and close the doors.
- Clearance time, which includes any re-entry delay due to waiting in turn for any buses at leading loading areas that are blocking the subject bus to depart, plus any re-entry gap acceptance delay.

The dwell times, in term of passenger - bus interaction, can be defined as the total time consumed by the bus to interact with passenger(s) at any give busway station, including door opening and closing time. Rajbhandari et al. (2003) termed the average passenger boarding and alighting time and bus dwell times at stops as the important information for estimating service capacity of the transit network. Having larger dwell times can be one of the reason of slow bus service (Schaller consulting, 2003) and may reduce service capacity of the bus and transport network. The TCQSM, 2003 defines the dwell time as the time required to serve passengers at the busiest door, plus the time required to open and close the door. Mathematically, it can be represented by Equation (1). This is essentially the same equation as given in Vuchic (2005) for the same situation.

$$t_d = P_a t_a + P_b t_b + t_{oc} \qquad \text{Equation (1)}$$

Where,

t_d	=	Average dwell times (s)
P_a	=	Alighting passengers per bus through the busiest door (p)
t_a	=	Alighting passenger service time (s/p)
P_b	=	Boarding passengers per bus through the busiest door (p)
t_b	=	Boarding passenger service time (s/p)
t_{oc}	=	Door opening and closing times (s)

On the Brisbane network a busway station platform, in general, has three to four loading areas. During the peak hours when more buses enter the station in very short time intervals, a state of dilemma may occur in the mind of the passenger about the stopping location of their desired bus on the platform. This ultimately leads to the crowding of passengers between the leading end and the middle of the platform. Crowding reduces manoeuvring capacity and comfort level of passenger (TCQSM 2003). It also reduces their walking speed thus increasing bus dwell times. The line of sight of the passenger may become obstructed because of the crowding.

During the peak hours when the number of buses on the network is highest, the third and fourth loading area of the platform, where available, are more likely used by buses. The passengers standing between the lead stop and the middle of the platform then have to walk further to reach their bus, if it is standing at the rear stop. This increases the bus dwell time.

In addition to understanding bus dwell times to determine bus delays through stations, dwell times also affect the bus handling capacity of the loading areas and therefore the bus capacity of the station platform as a whole. Bus platform capacity is critical as it may create a bottleneck in the system.

The capacity of each loading area is given by Equation (2) (TCQSM, 2003) which has been reduced to exclude the effect of signalised intersections and to assume a 50 percent probability of a loading area being occupied when the next bus arrives to use it (i.e. no operating margin).

$$B_1 = \frac{3{,}600}{t_c + t_d} \qquad \text{Equation (2)}$$

Where,

B_1	=	Loading area bus capacity (bus /h)
3,600	=	Number of seconds in 1 hour
t_c	=	Clearance time of bus
t_d	=	Average bus dwell time (s)

3 Bus bunching

Prediction of running time and forecast of arrival time of the buses at stations may be difficult due to the uncertainty of bus dwell times required. Lateness or earliness of bus arrivals at a given station depends on the dwell times at all the upstream stations. To increase in the public transport patronage, bus arrival time forecasts should be accurate as the daily commuters prefer to arrive at the station very near to the arrival time of their service. The passengers whose desired bus is running behind schedule incur additional delay. In the mean time, more passengers for the next bus on the same route arrive at the station. This situation may lead to congestion at the station. When the bus that is running late arrives at the station, both sets of passengers boards the bus, increasing its dwell time and further escalating its delay. In other words; later the bus, the longer its dwell times and vice versa (Shalaby, 2004). This leads to the recurrence of these events at all down stream stations. At the same time a bus of the same route following the delayed bus has fewer passengers to board and alight and can catch up to the first bus causing bus bunching.

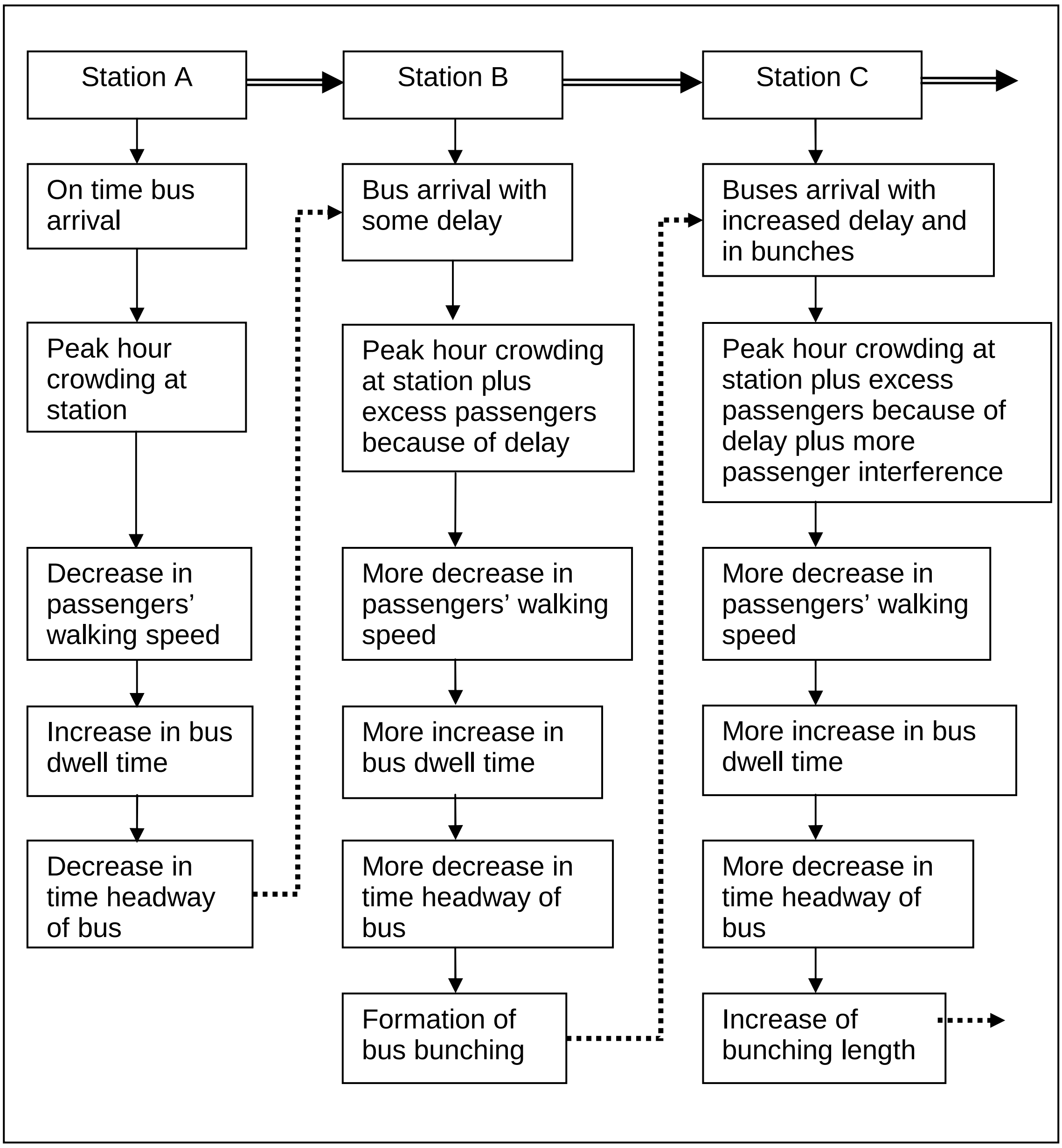

Figure 1 Inter – station interference with bus dwell times at peak hour

Bus bunching is not desirable as it reduces the efficiency of the network. The compromised operation of one station has effects on the downstream stations as illustrated in Figure 1. Suppose a bus arrives 'on time' at station A and experiences peak hour passenger crowding at the station. The increased passenger crowd decreases the space available per passenger for walking, reducing their walking speed. In such cases the bus driver has to wait until all passengers reach the bus door and board. The bus needs to spend more time at the station and hence increases its dwell time and reduces the time gap allotted between the two bus arrivals causing a decrease in their headway.

Further, when this bus reaches the next station (station B) and experiences the similar situation, the headway between the two bus arrivals reduces further. At some point in time this headway will be very small forcing buses to run one behind other forming 'bus bunching'. When this bunch of buses reaches to the next station (station C) and finds the same situation, the delay with dwell time further increases because more passengers are boarding and alighting, increasing their interference. This situation is not attractive from the point of view of passenger as it may create uncertainty.

Many researchers have tried to highlight the importance of uncertainty of waiting time and trip time in evaluating airport terminal performance (Cokasova, 2005; Lemer, 1992), but not much has been done to find the effect of uncertainty occurring at busway stations. What's true with the airport terminal performance evaluation is also holds for busway station performance evaluation. The uncertainty with transfer time and waiting time may reduce the quality of service of the system and may lessen the commuter's faith with the public transport system.

In future, the demand for public transport will increase. It is therefore necessary to understand the passenger movement at the busway station and their interaction with the bus. A streamlined interaction is essential from the view point of both passengers as well as bus operators. The focus of this paper is on understanding the effect of bus dwell times over the loading area capacity of the busway station.

The objective of this research is to better understand the effect of passenger crowding at the station on the bus dwell times as part of overall bus delay, and in future research its effect on downstream stations. Despite the fact that such passengers crowding is, generally, presently occurring only during the peak hours, it has the ability to reduce the travelling speed when speed matters most. The objective is divided into two parts - first to understand the effect of crowding on bus dwell times at a subject station and second to understand the effect of change in bus dwell times at subject station on the downstream stations, which will be covered in future research.

4 Pilot Study Methodology

In conducting a pilot study of bus dwell times and the capacity of a busway station platform many parameters have been considered. The following text illustrates these details.

4.1 Characteristics of buses using the station

The busway road-side parameters such as bus characteristics interface with platform-side parameters such as crowding. The number of passengers a bus can carry depends on its seating capacity. Understanding the characteristics of bus operation at these stations thus becomes necessary. Some buses on the high demand routes are articulated to increase the passenger carrying capacity. These buses not only require more than one loading area, they also have higher dwell times because of large crowd formation at their busiest (boarding) door. Similarly, it is equally important to know whether the buses are low floor or high floor, they have marginally different passenger service times and onboard capacity.

4.2 Analysis period characteristics

It is essential to consider the correct peak time for the analysis as transport system performance is stressed during certain times of the day only. The characteristics of the South East Busway corridor are such that, during the morning peaking, flow of passengers toward the city is high, contributing to high numbers of passenger alighting at inner inbound platforms. During the afternoon and evening peaks there are more boarding passengers at the outbound platforms of inner stations. For boarding passengers, though they choose their origin i.e. the entry point to station, they are uncertain of the location of their destination point on the platform i.e. in which loading area their service will stop. Another visible difference between the morning and evening peak hours is the number of onboard ticket purchases. In the evening peak time, the number of passengers having pre-purchased ticket is higher and hence, for boarding passengers, less on board ticket purchasing occurs during evening peak than in morning peak. This is, however, offset by the fact that there are more alightings than boardings at inner stations during the morning peak.

Because of the large numbers of passenger and bus flows at the station during the study time, the data collection method should be decided with care. On site manual counting can prove to be very laborious and may be susceptible to high human error. Video recording of the station and then laboratory counting can be an alternative which eliminates much of the possible error.

4.3 Observation at the station

The aim of the observation is to gather the evidence of how the passenger – bus interaction takes place at the station. It the therefore important to record the bus type and characteristics such as bus route number, vehicle type, numbers of door and so on. Also it is equally important to record the passenger flow to relate it to crowd formation and identify the location of crowding at the platform.

4.4 Analysis of observation

In this segment, the analysis of the data collected during the observations made in the previous section will be done. This will provide the critical understating of the operational efficiency of the station under study. With video observation used, each bus upon entry at the station is monitored. Their times of entry and exist to the station along with the clearance are recorded. In a station having multiple loading areas, the amount of time the empty loading area is blocked by another bus is an important parameter to determine the efficiency of all available loading areas. The duration for which each empty loading area is not able to be occupied due to a blockage can be determined to calculate the efficiency of each available loading area.

The next step is to record the numbers of passengers boarding and alighting. The time lapse between door opening and the boarding of first passenger for each bus is noted.

4.5 Interpretation of results

The results obtained from the analysis are compared with the values stated in the Transit capacity and Level of Service Manual (TCQSM, 2003). This comparison will give an insight to the present operating condition of the busway station compared with expected conditions.

5 Pilot study

For the pilot study, the peak direction platform at Mater Hill Busway station during the afternoon peak hour was outbound. From Brisbane city, Mater Hill station is the third station on the 16 km long South East busway corridor as shown in Figure 2. Mater Hill Busway station has three unmarked loading areas as shown in Figure 3. During the peak hours some buses stop very close to the dwelling bus in front thereby creating a temporary fourth loading area.

The outbound platform of the station has two non-continuous p.m. peak periods (Lee, 2004). The first afternoon peak occurs because of the arrival of the school students and the second, evening, peak occurs because of the arrival of Hospital and other institutions' employees. The pilot analysis period was between 3:00 pm and 3: 45 pm on a school day, which covers the first peak. On the day of video observation at the station, the weather was rainy. This weather condition is expected to have affected the station performance and this may be reflected in the results.

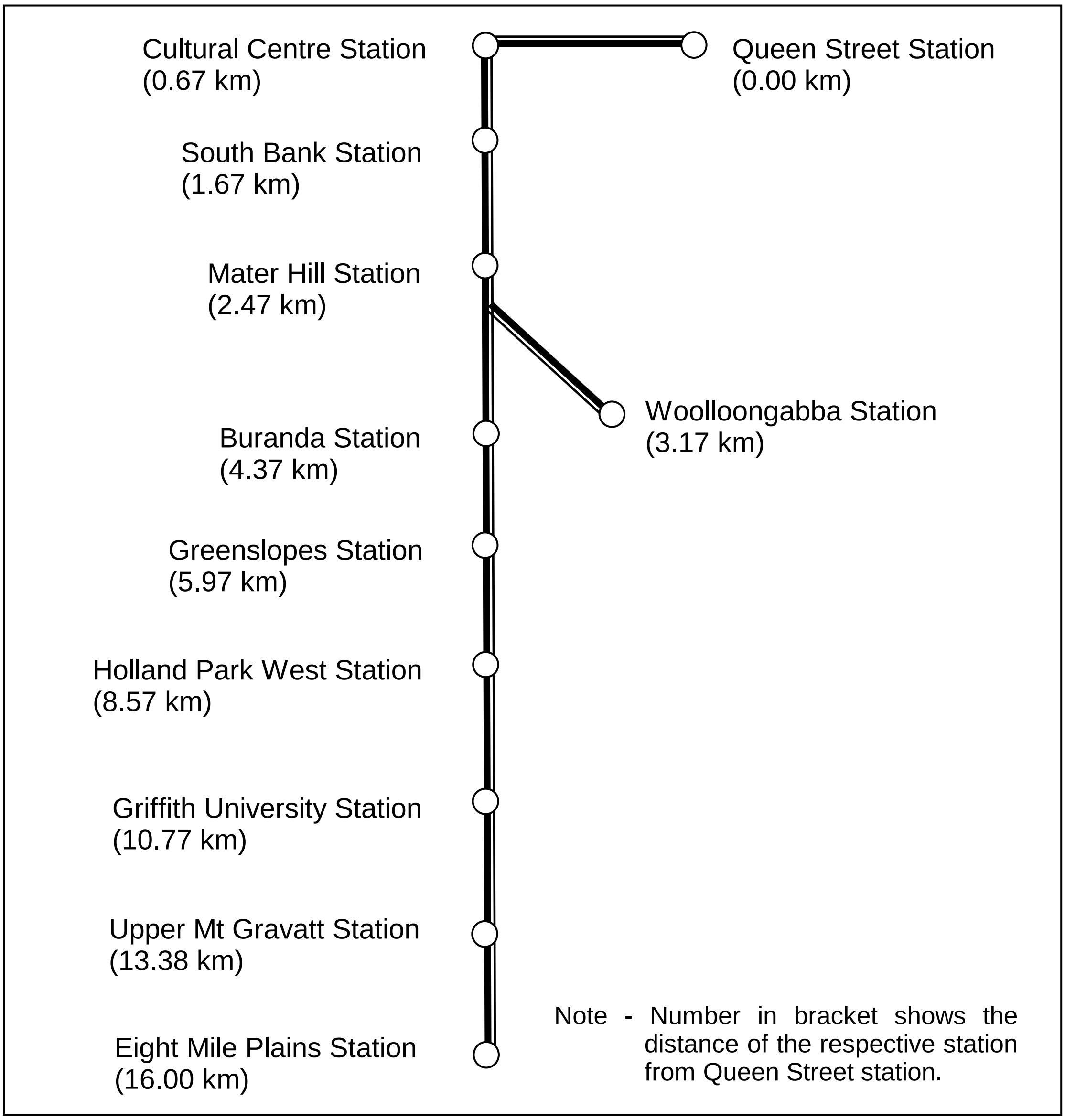

Figure 2 South East Busway route map

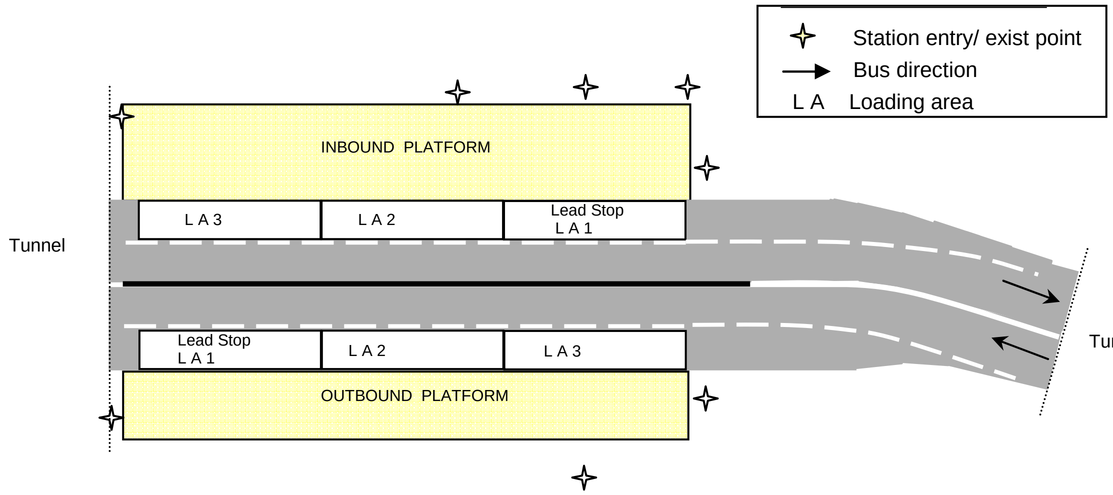

Figure 3 Configuration of Mater Hill Busway station

5.1 Loading area and bus dwell times

Table 1 shows the variation in bus dwell times and bus service time per passenger for each loading area. It was found that the average bus dwell time for loading area 3 is higher than that of loading area 1 by 32.7%. The values for average passenger service time were much higher than the values given in TCQSM, 2003 and generally higher then those of Vuchic, 2005. One of the reasons for high service times for loading area 3 was found to be larger distance for the passengers to travel to the bus door. This can be seen from the mean and standard deviation of the time lapse between the bus stopping and first passenger boarding given in Table 2. Low walking speed is an influence here passengers are frequently obstructed because of the crowding at the platform area. Another factor which increases the dwell time is that some passengers purchase a ticket from the driver at the time of boarding. The effect of purchasing an on-board ticket may vary, such as, when exact change was provided to the driver or when the exact change was not given or the correct fare is not known.

Table 1 Bus dwell times and service time at Mater Hill Busway Station

	Loading Area 1	Loading Area 2	Loading Area 3	TCQSM, 2003 Value	Range (Vuchic,2005)
Average bus dwell times (s)	37.6	49.2	49.9	-	-
Average bus service time for boarding passenger (s)	4.8	5.9	12.7	3.5	3.0 – 5.0
Average bus service time for alighting passenger (s)	2.2	1.9	2.1	2.1	1.5 – 3.0

Table 2 Time lapse between bus stopping and first passenger boarding

	Loading Area 1	Loading Area 2	Loading Area 3
Mean	3.3	3.5	4.6
Standard deviation	2.1	2.6	2.6

5.2 Analysis of Number of Effective Loading Areas

A 45min video record was analysed to extract the data. Time in queue and average dwell time for buses were measured.

From the literature it is clear that the efficiency of the loading areas influences the bus capacity of the station. The TCQSM, 2003 describes the notion of the effectiveness of loading areas at a bus stop. This same notion has been applied in this research, this time to calibrate the effectiveness of loading areas at a subject Busway station platform.

Mater Hill Busway station reaches its ideal bus capacity when all the three loading areas are occupied by the buses. However, as the buses use the loading areas on a first come first in basis, the station may reach a non-ideal capacity when one or both of the loading area 1 and 2 are empty but a preceding loading area is occupied.

The efficiency of loading area 3 is 100 percent as it is always able to be occupied while there is a queue present.

However, loading area 2 will not be 100 percent efficient. The efficiency of loading area 2 of the platform at the station is given by Equation 3. Theoretically loading area 3 will not be blocked at any time because no bus will stand in queue if loading area 3 is empty. But a bus on loading area 3 can block the entry to empty loading area 2. For instance, consider that all the loading areas are occupied by the buses and there is a bus queue behind loading area 3. A bus on loading area 2 moves out of the platform making this loading area available for next bus. But if the bus on loading area 3 was still dwelling at the platform it blocks the entry to loading area 2. The amount of time that loading area 2 is blocked because of the presence of a bus on the loading area behind them was recorded as blocked time. The efficiency of loading area 2 is given by Equation (3).

$$E_{LA2} = \frac{T_3 - T_{2,b}}{T_3} \qquad \text{Equation (3)}$$

Where,

E_{LA2}	=	Efficiency of loading area 2
T_3	=	Total time that loading area 3 is occupied during time T
$T_{2,b}$	=	Total time that loading area 2 was empty while a bus occupied loading area 3 during time T
T	=	analysis period

Similarly a bus on loading area 2 or loading area 3 can block loading entry to empty loading area 1. The efficiency of loading area 1 of the platform at the station is given by Equation (4).

$$E_{LA1} = \frac{T_{2,3} - T_{1,b}}{T_{2,3}} \qquad \text{Equation (4)}$$

Where,

E_{LA1}	=	Efficiency of loading area 1
$T_{2,3}$	=	Total time that loading area 2 OR loading area 3 OR loading areas 2 and 3 are occupied during time T
$T_{1,b}$	=	Total time that loading area 1 was empty while a bus occupied loading area 2 OR loading area 3 OR both loading areas 2 and 3

The number of effective loading areas (N_{el}) on the station platform may then be calculated using Equation (5).

$$N_{el} = 1.0 + E_{LA2} + E_{LA1} \qquad \text{Equation (5)}$$

Table 3 presents the calculation of the number of effective loading areas on the outbound platform at Mater Hill Station, during the pilot study, which occurred during the afternoon school peak period.

Table 3 Number of Effective Loading Areas Calculation for Bus Station Platform

Loading Area	Time preceding loading areas occupied	Time loading area empty while preceding occupied	Loading Area Efficiency	Cumulative Loading Areas
3	NA	NA	1.00	1.00
2	T_3 = 848	$T_{2,b}$ = 82	0.90	1.90
1	$T_{2,3}$ = 1304	$T_{1,b}$ = 372	0.71	2.61

The results indicate that the outbound platform of Mater Hill busway station has 2.61 effective loading areas out of the available 3 loading areas. It also shows that the cumulative number of effective loading areas for the platform does not increase linearly with the addition of physical loading areas. The results closely resemble the default values from TCQSM, 2003 as shown in Table 4.

Table 4 Comparison of results

Number of available loading area	Calculated	TCQSM, 2003 Cumulative Loading Areas for Comparison
1	1	1
2	1.9	1.85
3	2.61	2.65

5.3 Bus Station Platform Capacity

Capacity of the loading areas affects station platform capacity. Using Equation (2) the capacity of each loading area as per the TCQSM, 2003 was established. The clearance time for each loading area was taken as average of all clearance times observed in the data across all loading areas. It is recognised that further investigation needs to be done on clearance times at each loading area, as buses departing the second and third loading areas may be somewhat impeded by those buses dwelling ahead of them. Table 5 presents the capacity calculations.

Table 5 Capacity calculation for Bus Station Platform

Loading area	Bus clearance time (s)	Av bus dwell time (s)	Ideal Capacity (bus/h)	Efficiency E_{LA} (%)	Effective capacity (bus/h)	Measured hourly bus flow rate	Degree of saturation (%)
3	11	50	59	100	59	23	39
2	11	50	59	90	53	32	60
1	11	38	74	71	52	37	71
Total					164	92	56

The total effective capacity calculated for the station outbound platform was 164 bus/h yielding an overall degree of saturation of 56 percent, which accords with observations on the day. Once every few minutes (13 times in 45 minutes) queues extended beyond the number of loading areas on the platform, however the loading areas were periodically empty as well. The degree of saturation increases from loading area 1 to 2 to 3, which reflects the "lead stop" operation on the platform where the bus operator is instructed to stop as close as possible to the downstream or front end of the platform.

Table 6 compares the analysis results with values calculated using the TCQSM, 2003 assuming the default 3.5s boarding time per passenger, a 3.5s door opening and closing time, 1 passenger alighting per bus through the front door, 7 passengers boarding per bus on loading areas 1 and 2, and 3 passengers boarding per bus on loading area 3 (alightings and boardings as per field measurements).

Table 6 Comparison of results

Loading area	Ideal Capacity (bus/h)	TCQSM, 2003		Calculated		TCQSM over-estimation
		Efficiency	Effective capacity (bus/h)	Efficiency	Effective capacity (bus/h)	
3	126	1	126	1	59	+113%
2	85	0.85	72	0.9	53	+36%
1	85	0.8	68	0.71	52	+31%
Total			266		164	+62%

It is clear that for this particular station platform, that the TCQSM procedure substantially overestimates capacity, for the following reasons:

- Passenger service times on loading areas 1 and 2 were significantly higher at this station than the default service time listed in the TCQSM, which was demonstrated in Table 1. This may be due to the existing ticketing system used in Brisbane where drivers are still expected to sell tickets to passengers requiring change, and where some buses are experiencing problems with ageing magstripe card readers.
- Passenger service times on loading area 3 were extremely higher at this station than the TCQSM default due to the above reason as well as the dwell time "spent" while boarding passengers walked from their waiting position to the entry door of the bus at the rear end of the platform.
- Further, the wet weather on the survey day may have contributed to higher service times.

6 Future work

This paper presented a pilot study of bus and passenger operation at a busway station in order to examine passenger service times and station platform bus capacity. It has been demonstrated that a suitable method can be used to establish these measures. This methodology will be applied under a broader range of station and bus operating conditions and under different environmental/weather conditions to obtain a wider range of values. The methodology will be extended to also provide an understanding of bus delay through station platforms.

The effect of the proposed implementation of the "Smartcard" automatic fare collection system on passenger service times and bus station efficiency will be studied.

In future, the understanding developed in the pilot study will be applied to individual passenger – bus interaction and the effect of the prevailing level of service at one station on the other downstream stations along the line. VISSIM 4.2 micro-simulation software is proposed to be used to simulate bus and station passenger operations and the inputs required for simulation would be extracted from the CCTV recording. In order to get realistic queuing during simulation at Mater Hill station and its effect on operational efficiency of Mater Hill station, passenger - bus interaction attributes will be provided at upstream stations.

7 Conclusions

Public transport in Brisbane is experiencing a huge rise in demand and further rises are expected. In response, construction of new Busway systems has occurred and the numbers of buses on the existing system is increasing. The increased patronage and bus supply could make the passenger - bus interaction more difficult. The high dwell times have a significant contribution in reduction in overall effective station platform bus capacity compared to the expected values using the defaults of Transit Capacity and Quality of Service Manual.

This study found that:

- Blocking of loading areas, particularly for the lead loading area, has a significant impact on the station capacity.
- The reduced efficiencies for loading area 1 and 2 can be a prominent factor leading to formation of bus queuing behind loading area 3.
- Excessive passenger service times for loading area 3 arise due to "spent" dwell time as passengers walk from their waiting position to the end of the platform.
- Field passenger boarding service times were significantly higher than the Transit Capacity and Quality of Service Manual default value, resulting in a substantial capacity over-estimate using the manual. However, loading area efficiencies were found to be very similar to TCQSM default values for a busway station.

It may be possible to reduce the bus dwell times and hence the delay at stations by providing conditions favourable to organised and structured interaction between passengers and buses. It is equally important that the very attractive features of public transport, such as reliability and hassle free boarding and alighting, should be maintained. This includes improved ticket processing on boarding. A methodology which can co-relate the station operation efficiency with the passenger load will be helpful in understanding a range of operating conditions. By addressing the difficulties associated with present passenger – bus interaction, increased patronage may be possible.

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